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(54) **INTENSITY MODULATED ARC THERAPY WITH CONTINUOUS COACH ROTATION/SHIFT AND SIMULTANEOUS CONE BEAM IMAGING**

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See application file for complete search history.

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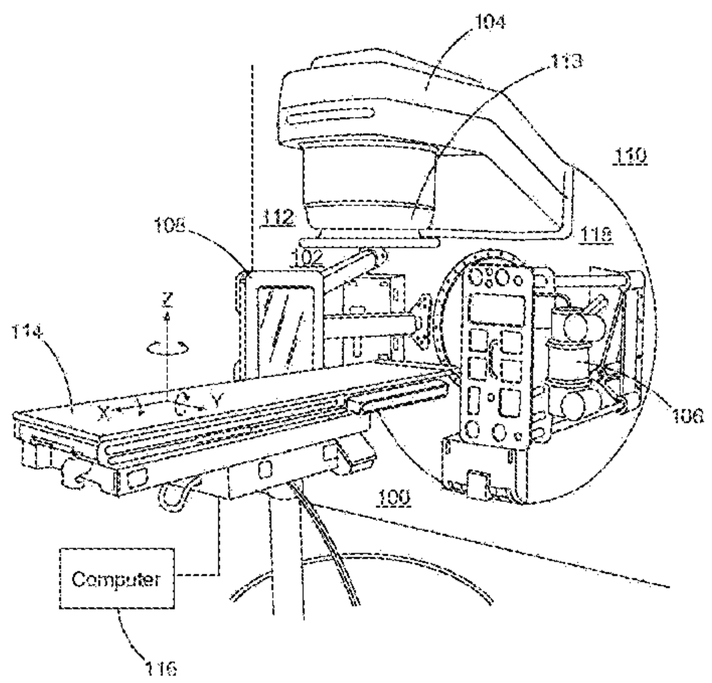
(57) **ABSTRACT**

A system for radiotherapy includes a couch having a top lateral surface upon which a patient being treated by the system is positioned. The couch has continuous arc rotation for delivery of accelerated irradiation to the patient. The couch is movable rotationally and translationally. Delivery of the accelerated irradiation is performed during at least a portion of the movement.

26 Claims, 10 Drawing Sheets



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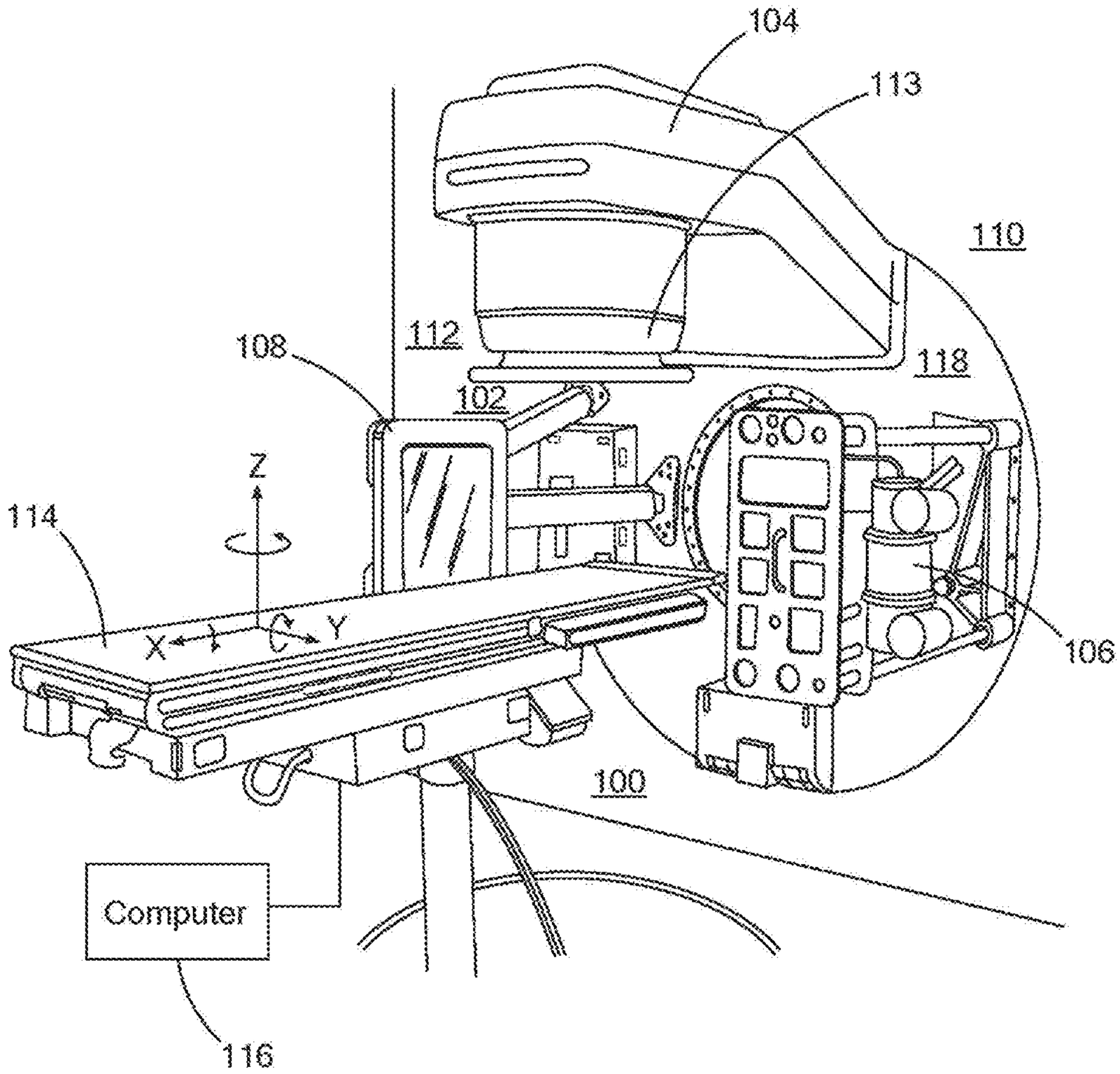

Fig. 1

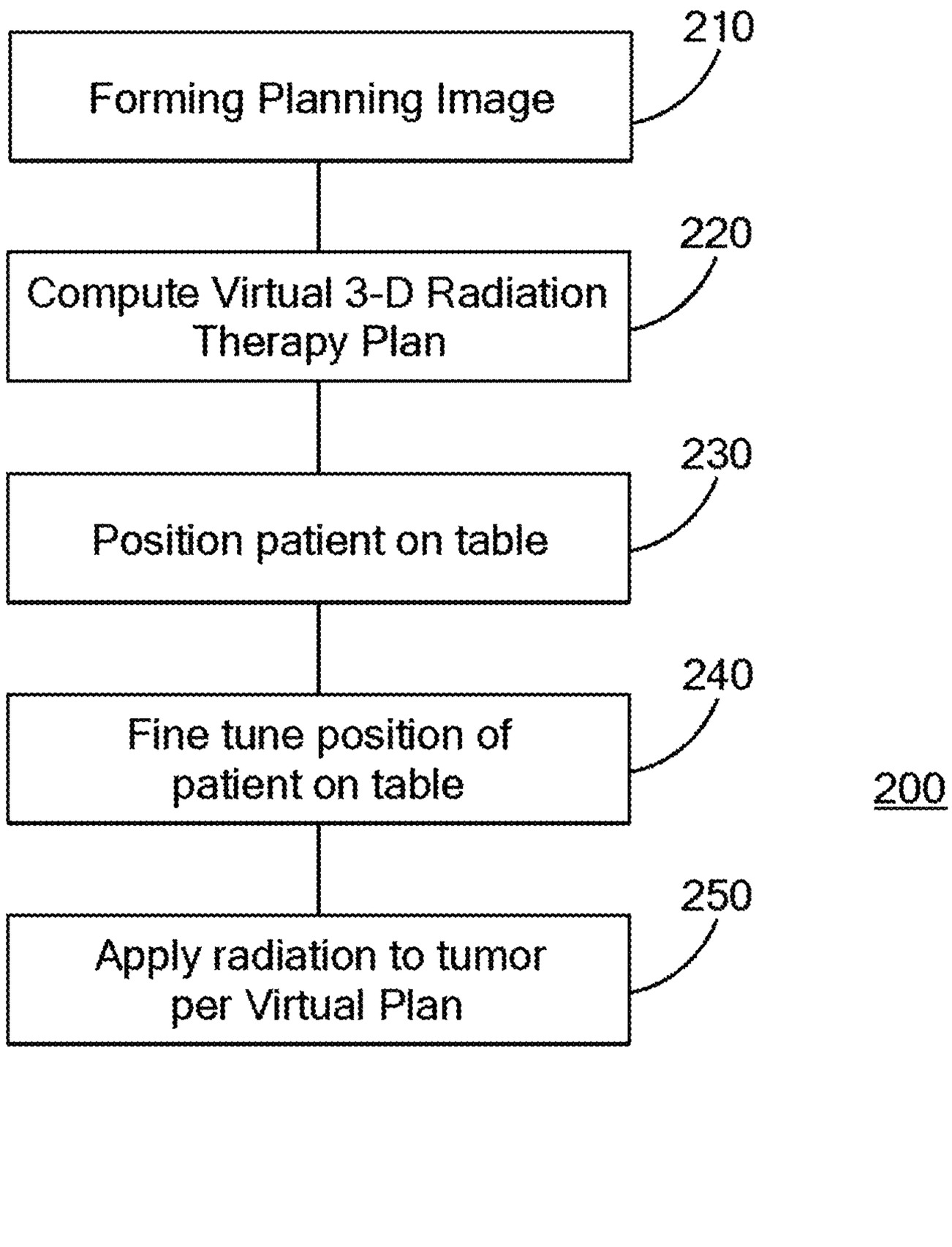
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Fig. 2

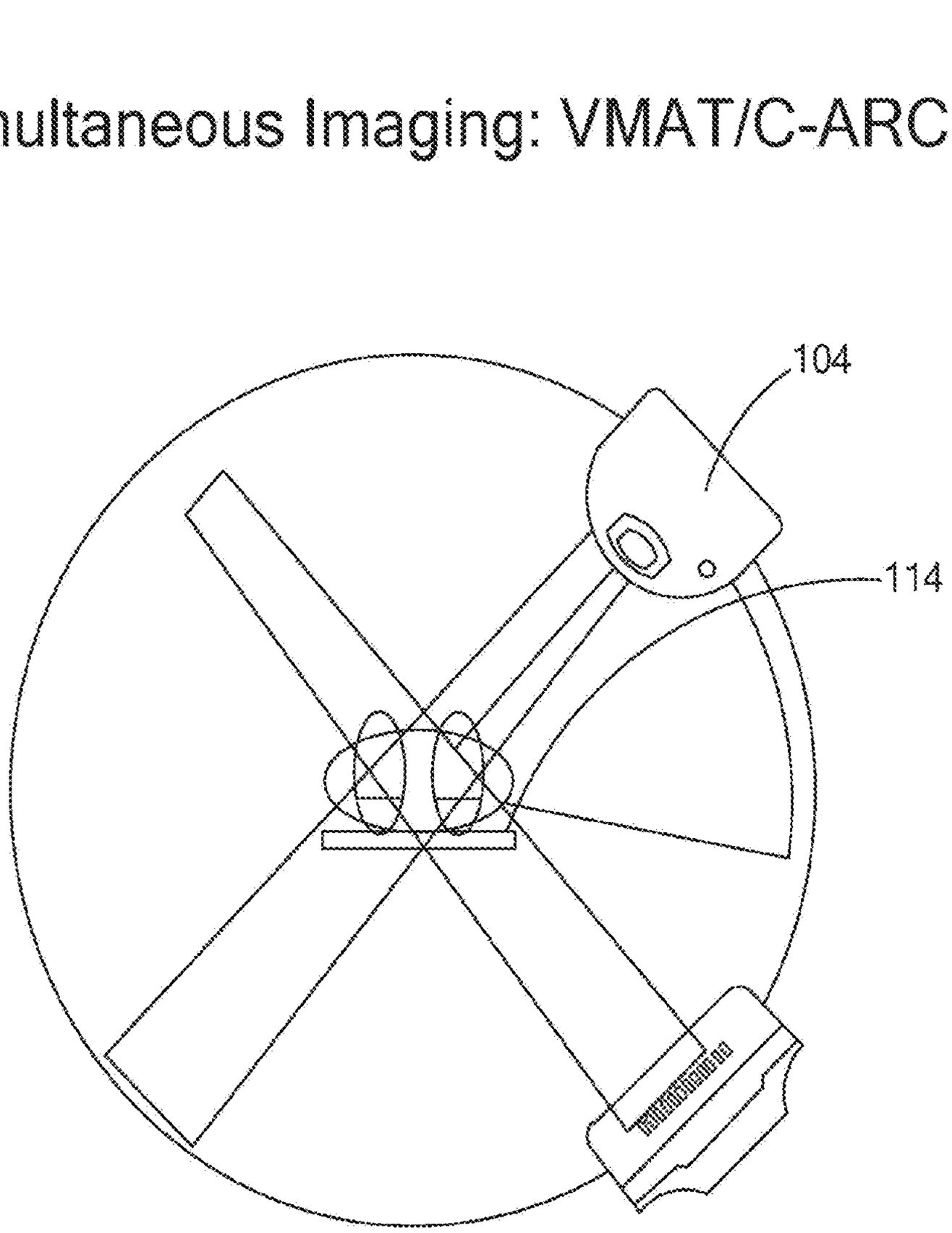


Fig. 3

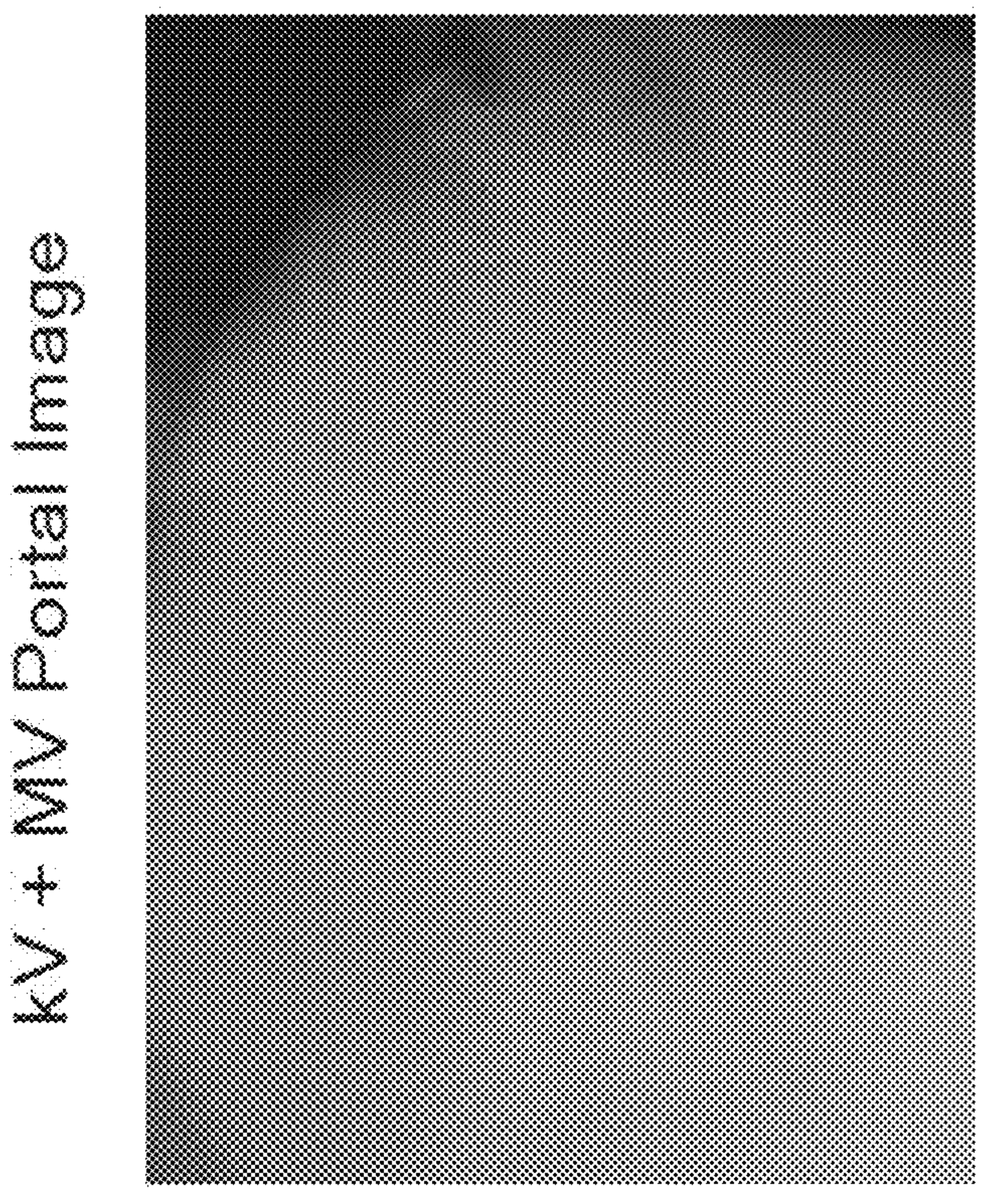


Fig. 5A

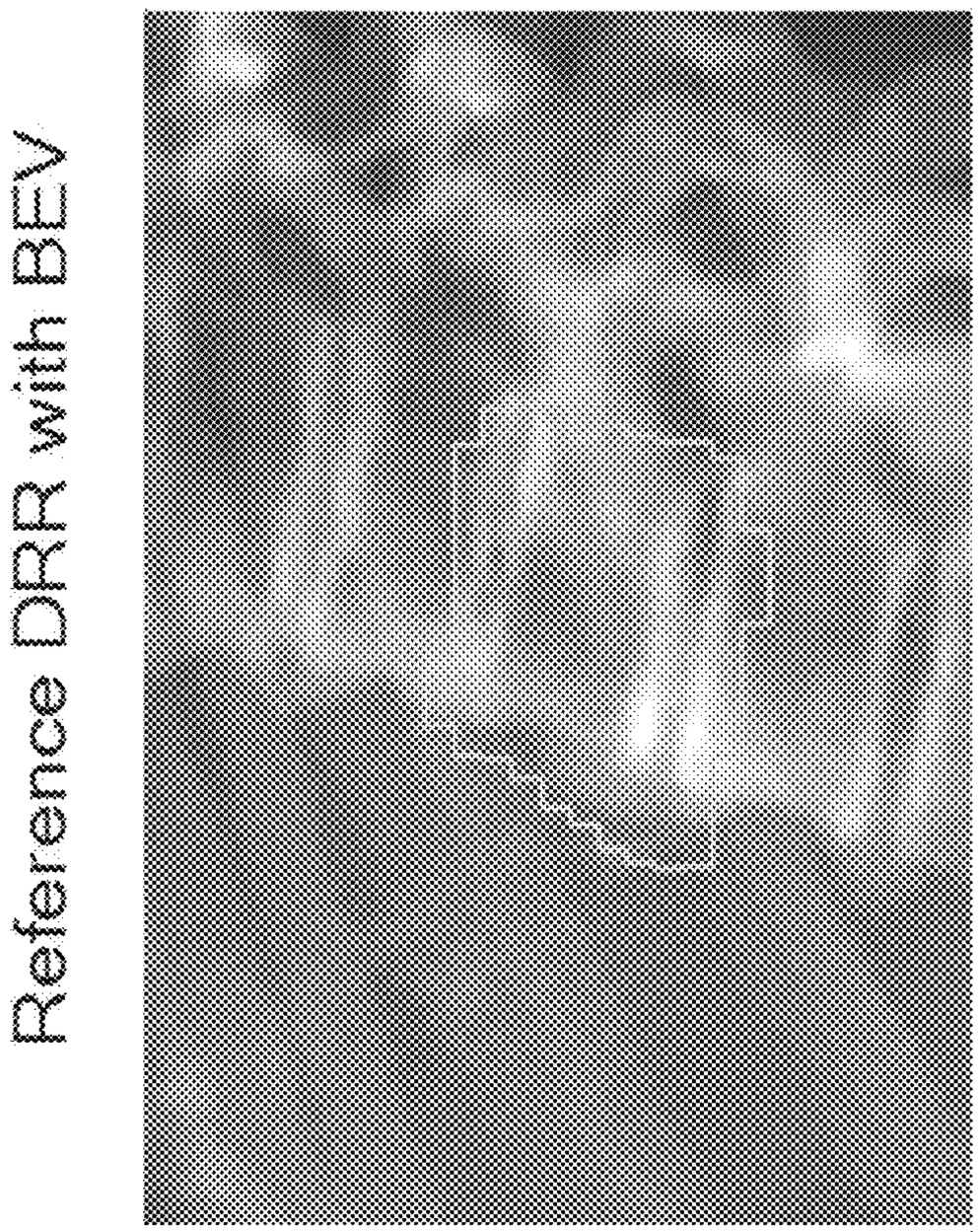


Fig. 4A

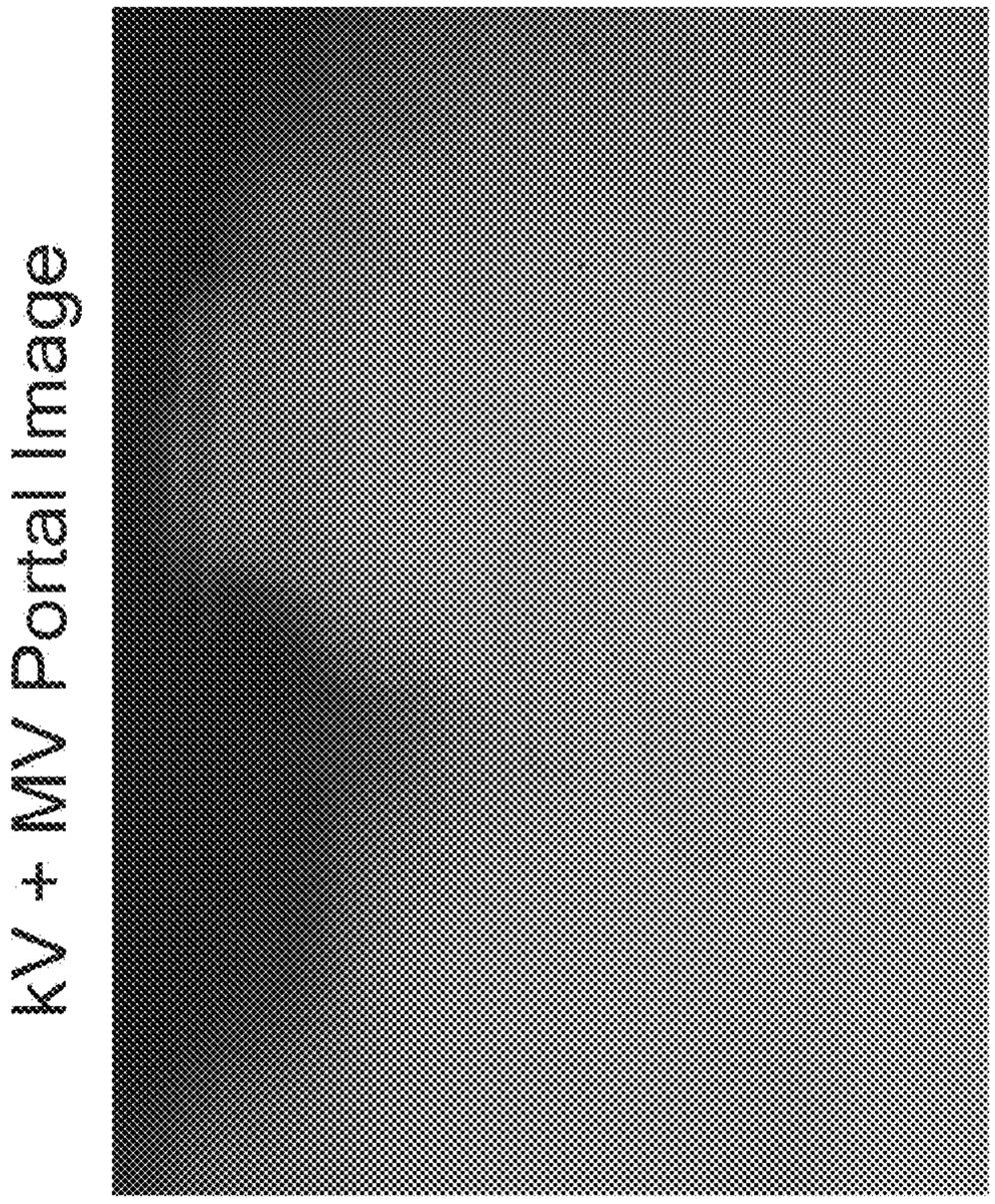
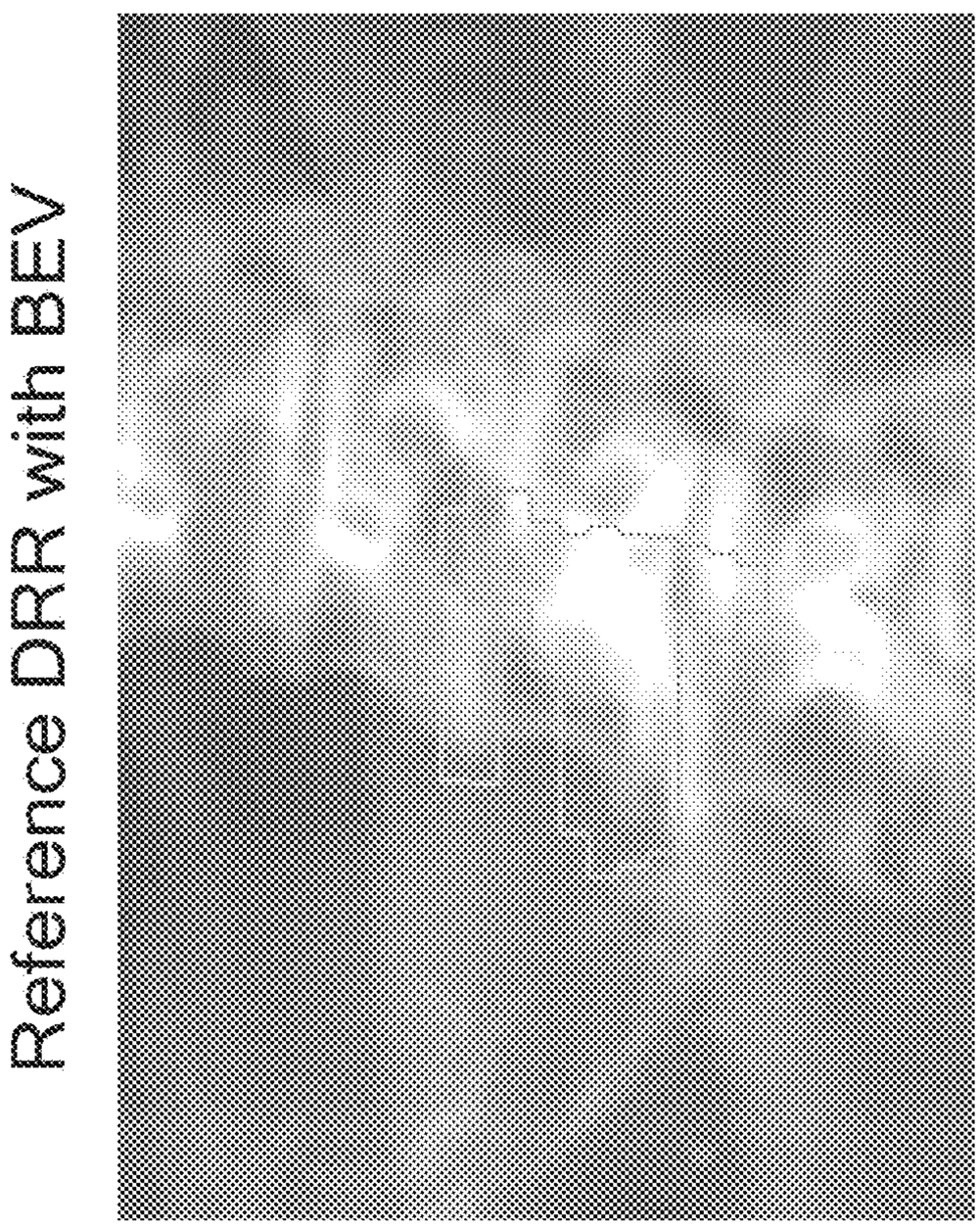


Fig. 5B



Gantry=135

Fig. 4B

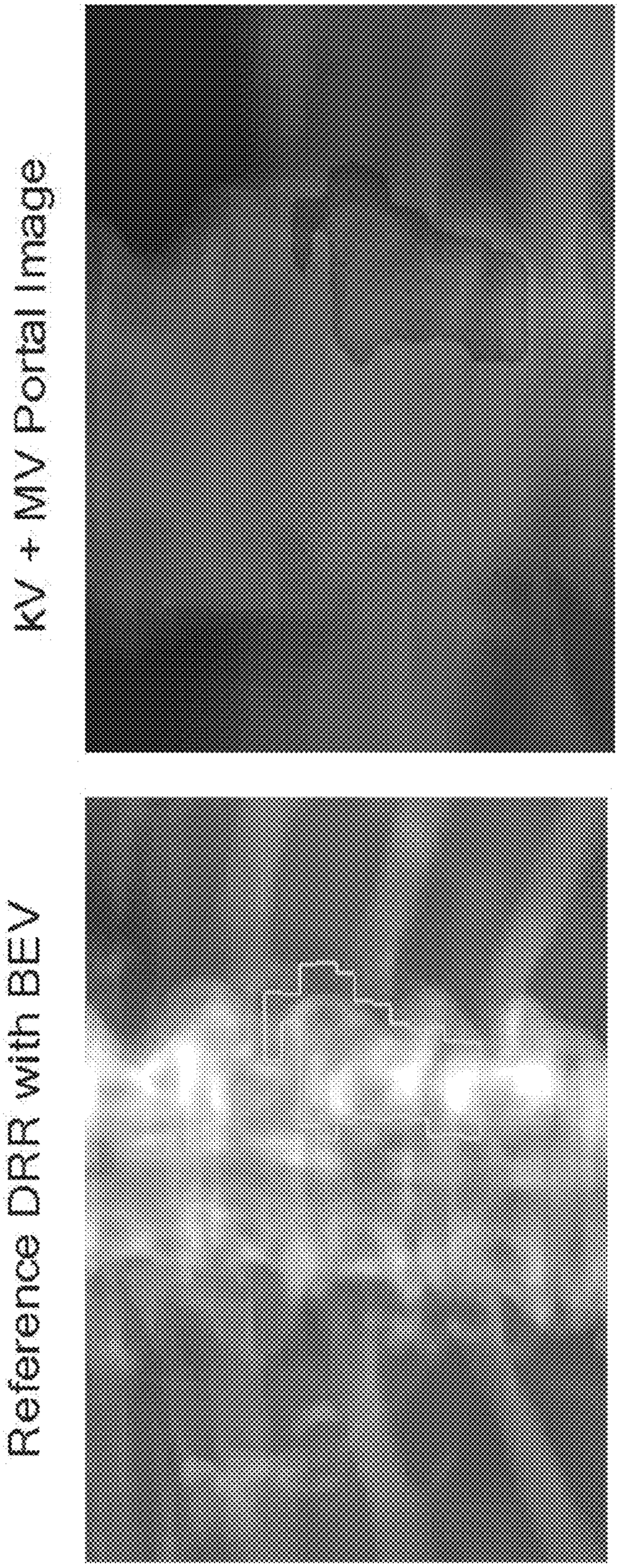


Fig. 5C

Fig. 4C

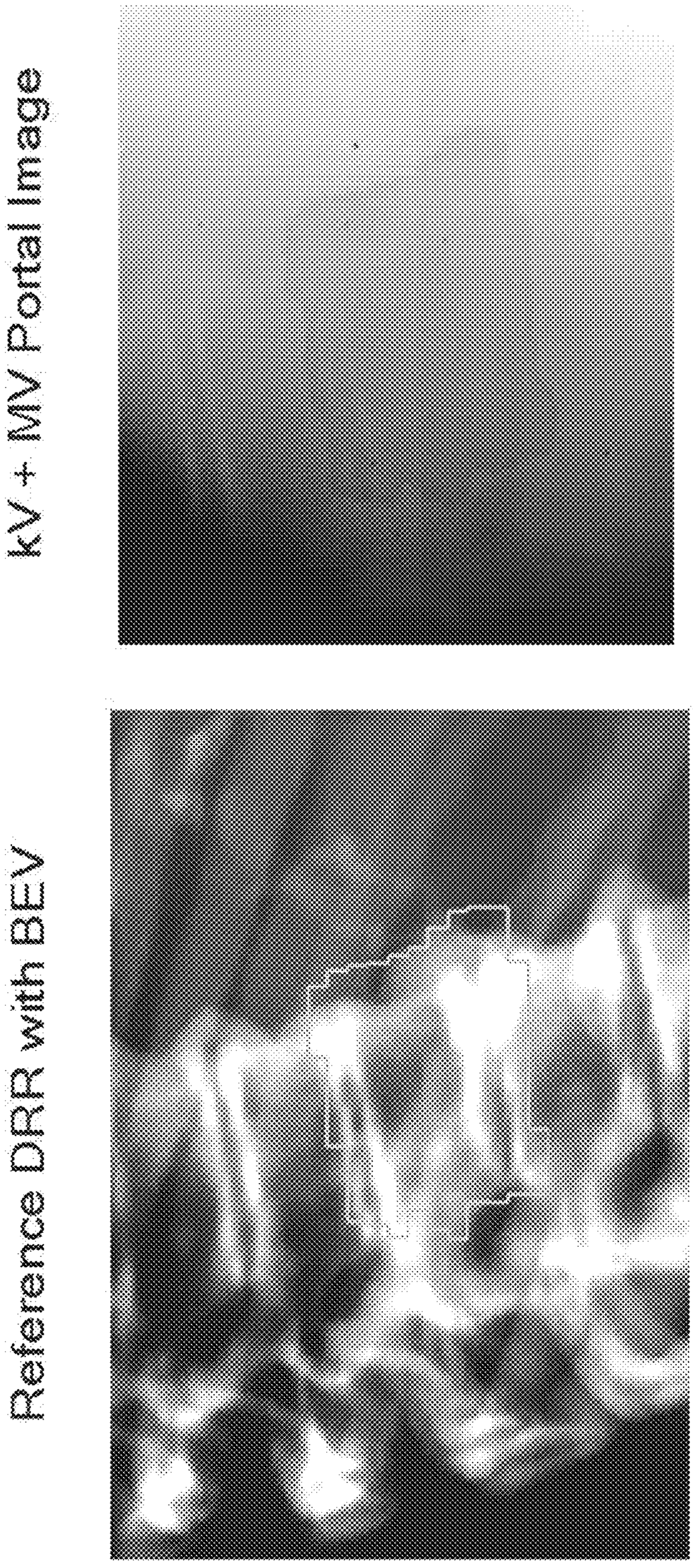


Fig. 4D

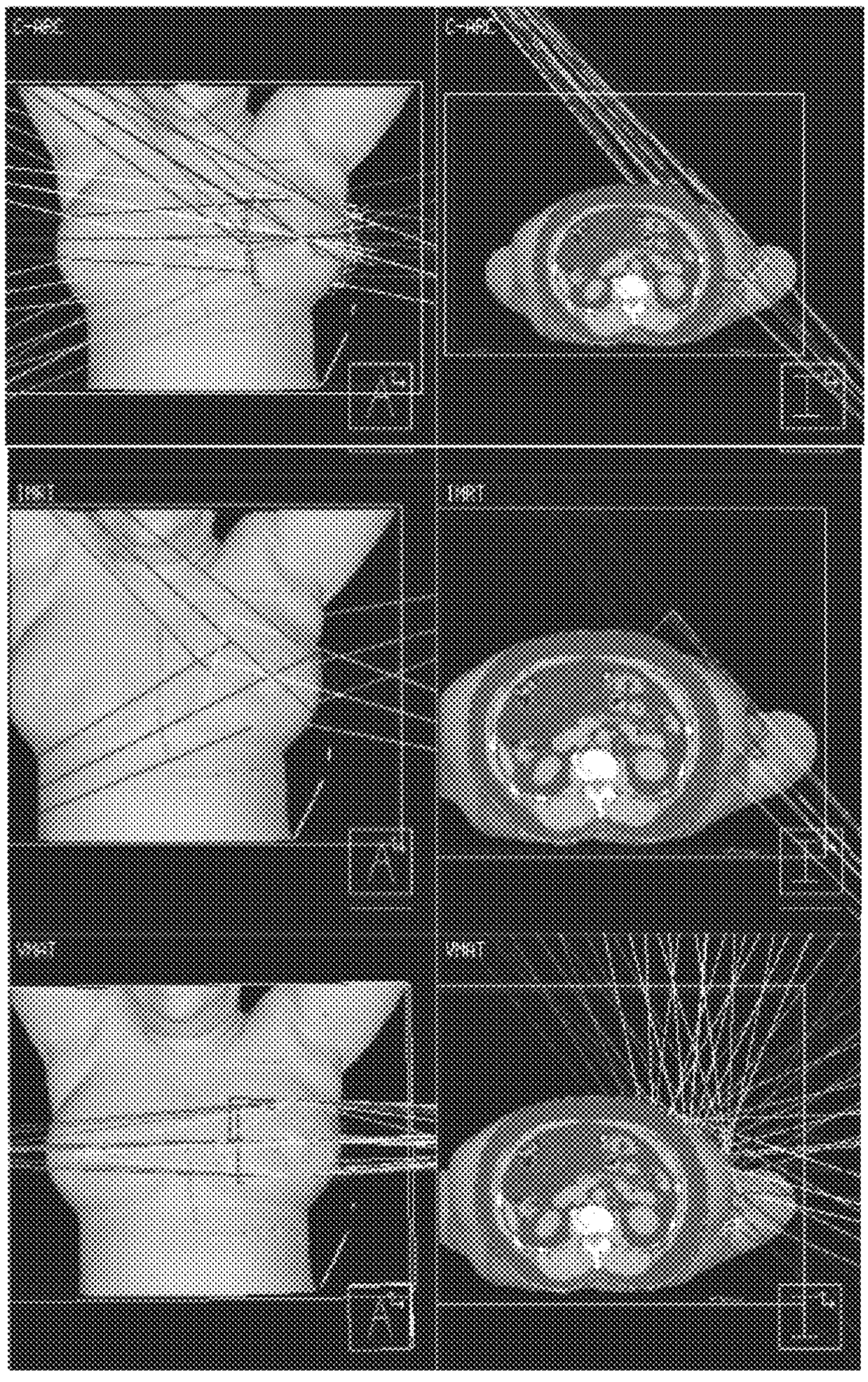


Fig. 6A

Fig. 7A

Fig. 6B

Fig. 7B

Fig. 6C

Fig. 7C

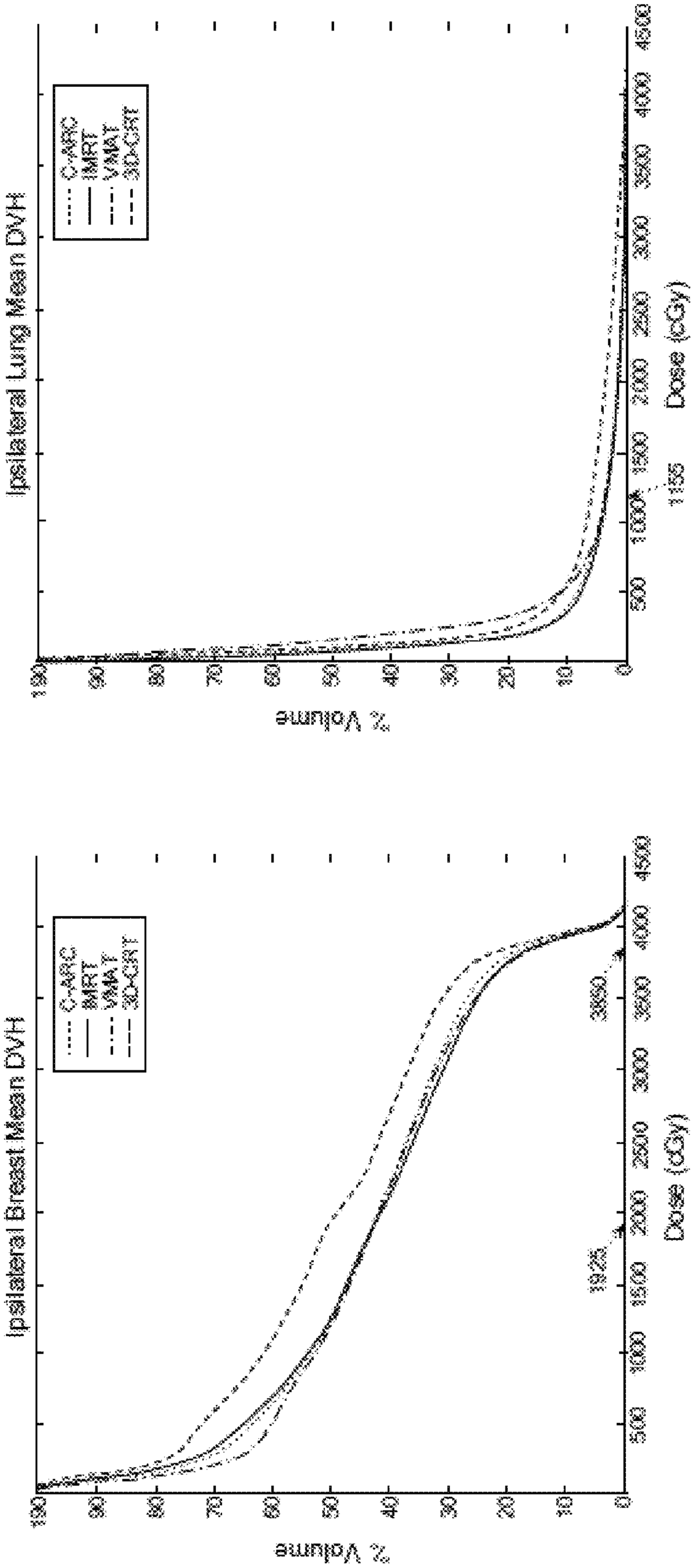

Ipsilateral Lung Mean DVH
C-ARC
IMRT
VMAT
3D-CRT
% Volume
Dose (cGy)
1155
Ipsilateral Breast Mean DVH
C-ARC
IMRT
VMAT
3D-CRT
% Volume
Dose (cGy)
1925

Fig. 8B

Fig. 8A

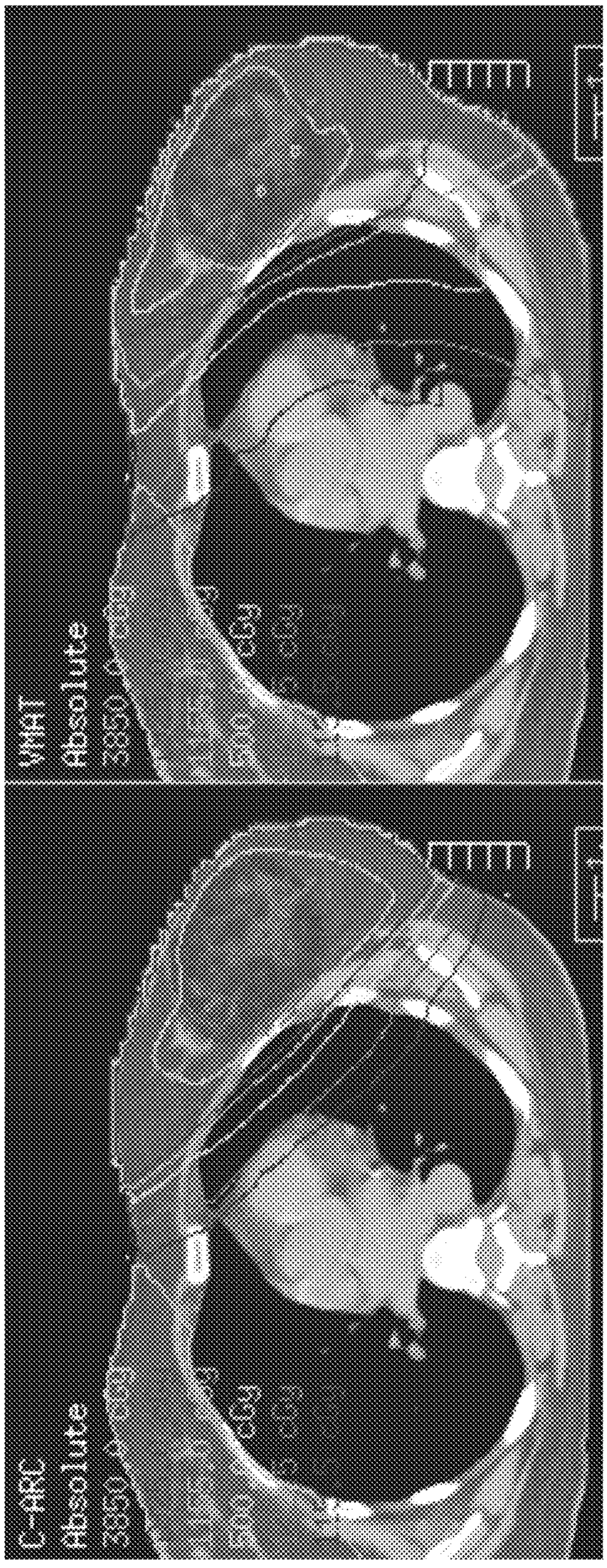

C-ARC
Absolute
3350 cGy
3350 cGy
VMAT
Absolute
3350 cGy
3350 cGy

Fig. 9A

Fig. 9B

INTENSITY MODULATED ARC THERAPY WITH CONTINUOUS COACH ROTATION/SHIFT AND SIMULTANEOUS CONE BEAM IMAGING

This application is a Continuation of application Ser. No. 12/930,348 filed on Jan. 4, 2011, which claims the benefit of U.S. Provisional Application 61/335,314 filed on Jan. 5, 2010, which is entirely incorporated herein by reference.

TECHNICAL FIELD

The present invention relates generally to systems and methods for treatment and delivery of therapeutic radiation and, in particular, relates to a system and method for additional continuous arc rotation/shift of a couch (C-ARC) in the volumetric modulated arc therapy (VMAT) delivery of therapeutic radiation, as well as simultaneous kV cone-beam imaging for real-time treatment verification and adaptation.

BACKGROUND

There are a number of known systems and method for treatment and delivery of therapeutic radiation. One of these is known as three-dimensional conformal radiation therapy (3D-CRT). 3D-CRT involves three-dimensional imaging, accurate radiation dose calculation, computer optimized treatment planning, and computer controlled treatment delivery. In particular, 3D-CRT uses computers and special imaging techniques such as CT, MR or PET scans to show the size, shape and location of a tumor as well as surrounding organs. The therapeutic radiation beams are then precisely tailored to the size and shape of the tumor with multileaf collimators or custom fabricated field-shaping blocks. The precise application of the therapeutic radiation beams results in nearby normal tissue receiving less radiation and so the normal tissue is able to heal more quickly after a therapeutic radiation session. The more normal tissue is shielded from receiving the therapeutic radiation allows for the amount of the radiation actually delivered to the tumor to be increased and so the chances of successfully treating the tumor increase. An example of 3D-CRT is described in the publication, Takahashi S, "Conformation radiotherapy: rotation techniques as applied to radiography and radiotherapy of cancer," Acta Radiol 1965, Suppl. 242.

Another system and method for treatment planning and delivery of therapeutic radiation is known as intensity-modulated radiation therapy, or IMRT. IMRT is a specialized form of 3D-CRT that allows radiation to be modulated, thus more exactly shaped to fit the tumor. In particular, IMRT involves breaking up the therapeutic radiation beams into many "beamlets." The intensities of each beamlet are then adjusted individually. Such adjustment of intensities allows for the radiation received by healthy tissue near a tumor to be further reduced when compared with 3D-CRT. An example of IMRT is described in the publication, A. Brahme et al., "Solution of an integral equation encountered in rotation therapy," Phys Med Biol Vol. 27, No. 10, 1982, pp. 1221-29.

A third system for treatment and delivery of therapeutic radiation is known as intensity modulated arc therapy (IMAT) and later volumetric-modulated arc therapy, also known as VMAT. VMAT addresses several of the disadvantages of IMRT, namely, increased treatment time by requiring a larger number of beam directions and the use of increased monitor units (MU). VMAT addresses these disadvantages by allowing continuous gantry/collimator rotation, leaf motion, and dose rate adjustment for treatment plan optimization where

dose is delivered during a single gantry arc of up to 360 degrees. The VMAT technique is similar to tomotherapy in that a full 360 degree range of beam directions are available for optimization, but is fundamentally different from IMRT in that the entire close volume is delivered in a single source rotation. An example of VMAT is described in: 1) Yu C. X. "Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy," *Phys Med Biol* Vol. 40, 1995, pp. 1435-1449, 2) Yu C. X., et al., "Clinical implementation of intensity-modulated arc therapy," *Int J Radiat Oncol Biol Phys* Vol. 53, 2002, pp. 453-463 and 3) Otto K., "Volumetric modulated arc therapy: IMRT in a single gantry arc," *Med Phys* Vol. 35, 2008. pp. 310-317.

VMAT involves, in part, using multileaf collimator (MLC) leaf motion and dose rate adjustment to modulate beam output intensity. In addition. VMAT delivers the modulated beam intensity output by rotating the gantry and collimator of a linac through one or more complete or partial arcs with the therapeutic radiation continuously on so that treatment times are reduced. During rotation of the gantry, a number of parameters can be dynamically varied, such as: i) the MLC aperture shape, ii) the fluence-output rate ("dose rate"), iii) the gantry rotation speed and iv) the MLC orientation. Being able to vary the parameters i)-iv) allows VMAT to reduce the need to use as many arcs, delivering fewer monitor units (MU) in a shorter time while providing dosimetry comparable to IMRT. While VMAT can take advantage of the above-mentioned four available variable parameters, it must do so while respecting the physical constraints of the linac and MLC—such as the maximum gantry speed, maximum leaf speed, the MLC orientation constraints and the available subdivisions of fluence-output rate.

Without dynamically controlling all machine parameters, specifically the orientations between machine and patient, during treatment delivery, current VMAT technology is limited for certain treatment sites. In the case of breast cancer treatment, it has been shown that VMAT applied to treat left-sided breast cancers with internal mammary node irradiation resulted in an increase in the volume of lungs, heart and contralateral breast receiving low dose (5Gy) irradiation compared to modified wide tangents. By definition, due to its configuration, VMAT used for breast irradiation contains beams directed towards the heart, lungs, and contralateral breast.

Another disadvantage of VMAT systems is that they do not integrate simultaneous kV imaging. Accordingly, such VMAT systems are not capable of real-time treatment verification

SUMMARY

One aspect of the disclosure provides a system for radiotherapy including a couch having a top lateral surface upon which a patient being treated by the system is positioned. The couch has continuous arc rotation for delivery of accelerated irradiation to the patient. The couch is movable rotationally and translationally. Delivery of the accelerated irradiation is performed during at least a portion of the movement.

In some examples, the couch has continuous translation for delivery of accelerated irradiation to the patient. The table is rotatable at least about a z-axis orthogonally extending through a lateral surface of the table. The radiation is delivered during at least a portion of the rotation about the z-axis. In some examples, the table is rotatable at least about a y-axis extending through a lateral surface of the table, and the radiation is delivered during at least a portion of the rotation about the y-axis.

The system may further include an imaging system to generate image information that identifies an object of interest within the patient to be treated by the accelerated irradiation. Additionally or alternatively, the image information may be formed in a real-time manner during the continuous rotation of the couch. Such information may be used to control continuous rotation of the couch in a real-time manner.

In some implementations, the image information may be formed in a real-time manner during the continuous rotation and translation of the couch. Such image information may be used to control continuous rotation and translation of the couch in a real-time manner. The continuous rotation and continuous translation of the couch may be based on image information of the patient generated prior to the patient being placed on the couch.

Another aspect of the disclosure provides a radiation therapy system including a radiation source, a multi-leaf collimator, a table upon which the object is positioned, and a computer. The radiation source moves about an object and directs a beam of radiation towards the object. The multi-leaf collimator includes a plurality of moveable leaves that define an aperture through which the beam is directed from the radiation source to the object. The table is translationally and rotationally movable. The computer is in communication with the radiation source, the multi-leaf collimator and the table. The computer simultaneously controls one or more of the following parameters of the radiation source, the multi-leaf collimator and the table: table motion, radiation source motion, fluence output rate, multi-leaf collimator orientation, and shape of the aperture. The computer is configured to cause delivery of the radiation during at least a portion of the movement of the table.

In some examples, the table is rotatable at least about a z-axis orthogonally extending through a lateral surface of the table. The radiation is delivered during at least a portion of the rotation about the z-axis. The table may be rotatable at least about a y-axis extending through a lateral surface of the table. The radiation is delivered during at least a portion of the rotation about the y-axis. In some examples, the table is rotatable at least about an x-axis extending through a lateral surface of the table, and the radiation is delivered during at least a portion of the rotation about the x-axis.

The system may further include an imaging system to generate image information that identifies an orientation of the object. The image information may be formed in a real-time manner during rotational and translational movement of the table. Such image information is used to simultaneously control one or more of the following parameters in a real-time manner: table motion, table motion speed, radiation source motion, fluence output rate, multi-leaf collimator orientation, and shape of the aperture. Additionally or alternatively, simultaneous control of one or more of the parameters is performed based on image information of the object generated prior to a patient containing the object being positioned on the table. In some examples, the object is a tumor.

Yet another aspect of the disclosure provides a method of providing radiation including directing a beam of radiation towards an object, defining an aperture through which the beam is directed to the object, and positioning a table having a top lateral surface upon which the object lies. The method also includes rotating the table at least about an axis thereof, wherein the beam of radiation is delivered to the object at least during a portion of the rotating. The method further includes simultaneously controlling, during the rotation, one or more of the following parameters: table motion, beam motion, fluence output rate, aperture orientation, and shape of the aperture.

In some implementations, the rotation is about a z-axis orthogonally extending through a lateral surface of the table. In some implementations, the rotation is about a y-axis or an x-axis extending through a lateral surface of the table. In some implementations, the method includes translating the table along an axis thereof, wherein the beam of radiation is delivered to the object at least during a portion of the translating.

The method may include generating image information that identifies an orientation of the object. The image information may be formed in a real-time manner during rotational and translational movement of the table. Such information is used to simultaneously control one or more of the following parameters in a real-time manner: table motion, beam motion, fluence output rate, aperture orientation, and shape of the aperture. The image information may be generated prior to a patient containing the object being positioned on the table, and wherein the simultaneously controlling is based on the image information.

The details of one or more implementations of the disclosure are set forth in the accompanying drawings and the description below. Other aspects, features, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an embodiment of a radiation therapy system that can perform C-ARC therapy in accordance with the present invention;

FIG. **2** shows a flow chart of a possible process for operation of the radiation therapy system of FIG. **1** in accordance with the present invention;

FIG. **3** schematically shows a system for simultaneous kV/MV imaging in accordance with the present invention;

FIGS. **4**A-D show reference digitally reconstructed radiographic (DRR) with beams eye view (BEV) images at gantry positions of 90°, 135°, 180° and 270°, respectively, for an Stereotactic Radiosurgery (SRS) treatment;

FIGS. **5**A-D show kV and MV portal images at gantry positions of 90°, 135°, 180° and 270°, respectively, for an Stereotactic Radiosurgery treatment;

FIG. **6**A shows an external view of a possible beam arrangement for breast tumor treatment in accordance with the present invention;

FIGS. **6**B-C show external views of beam arrangements for known breast tumor treatment plans;

FIG. **7**A shows an internal view of the beam arrangement for breast tumor treatment of FIG. **6**A;

FIGS. **7**B-C show internal views of the beam arrangements for breast tumor treatment of FIGS. **6**B-C, respectively;

FIG. **8**A shows the Ipsilateral Breast % Volume v. Dose plots of various known treatment plans when compared with a treatment plan in accordance with the present invention;

FIG. **8**B shows for the Ipsilateral Lung % Volume v. Dose plots of various known treatment plans when compared with a treatment plan in accordance with the present invention;

FIG. **9**A shows representative axial dose distributions for a treatment plan for breast tumors in accordance with the present invention; and

FIG. **9**B shows representative axial dose distributions for a VMAT treatment plan.

DETAILED DESCRIPTION

As shown in FIG. **1**, there is shown a radiation therapy system **100** that can include an imaging system, such as a cone beam computed tomography system **102**, and a thera-

peutic radiation source, such as medical linear source or accelerator **104**. The computed tomography system **102** includes an x-ray source **106** and a flat panel imager **108** mounted on gantry **110**. The details of the computed tomography system **102** is described in U.S. Pat. Nos. 6,842,502 and 7,471,765, the entire disclosures of each of which are incorporated herein by reference. Of course, other types of imaging systems, such as C-arm support cone beam systems and proton imaging systems, can be used without departing from the spirit of the present invention.

The system **102** is retrofitted onto an existing or new radiation therapy system **112** that includes a separate radiation therapy source, such as the medical linear source **104**, which operates at a power level to allow for treatment of a target volume in an object, such as a human patient. The medical linear source **104** generates a beam of x-rays or particles, such as photons, protons or electrons, which have an energy ranging from 4 MeV to 25 MeV. Indeed, the medical linear source **104** could be replaced with other radiation sources used for therapeutic treatment of patients without departing from the spirit of the present invention. The radiation therapy system **112** further includes a multi-leaf collimator (MLC) **113** that is movable as a unit and includes leafs that are movable so as to define an aperture for the therapy beam to pass through on to the patient. The radiation therapy system **112** may also include an imager (not shown) that is aligned with the medical linear source **104** with the patient interposed therebetween.

For support of the patient and for aiding in the application of the therapeutic radiation beam, a computer-controlled treatment table **114** is provided. The table **114** is controlled by a computer, such as computer **116** schematically shown in FIG. **1**. The table **114** allows translation of the patient in the x, y, and z directions as well as rotation about the x, y and z axes. Furthermore, the treatment table **114** is preferably constructed of radio-translucent material so as not to interfere significantly with the acquisition of computed tomography images. The table **114** can have many forms such as disclosed in U.S. Pat. Nos. 6,842,502 and 7,471,765 and U.S. Patent Application Publication No. US2010-0119032A1, the entire contents of each of which are incorporated herein by reference.

The system **100** of FIG. **1** is controlled by computer **116** so as to perform C-ARC therapeutic radiation treatment plans in accordance with the present invention. In particular, C-ARC, like VMAT, involves combining a modulated beam aperture and dose rate with rotational delivery. In contrast to VMAT, C-ARC introduces an alternative modality of delivering rotation. In particular, the table or couch **114** moves via translation and/or rotation so as to control therapeutic radiation delivery to the area of interest. Note that the translation of the table **114** can be in one or more of the x, y and z directions shown in FIG. **1**. In addition, the rotation of the table **114** can be in about one or more of the x, y and z directions. During rotation of the table **114**, the ring **118** of gantry **110** can also rotate simultaneously for certain treatment sites, such as the brain.

While the table **114** is moving, the aperture shape and the orientation of the MLC **113** can be dynamically varied. In addition, the fluence-output rate ("dose rate") and gantry rotation speed and consequently speed of rotation of the radiation source **104** can be varied. Control of the table motion, the gantry motion, fluence-output rate, MLC orientation and shape of the MLC is performed by computer **116**. The software used to control the computer **116** can be similar to software used in VMAT, wherein the software for C-ARC is such that clinically acceptable dosimetry is generated while avoiding any collision between the table **114**, gantry **110** and its attachments, and the patient. With the above description of the system **100** in mind, a possible process for operation of the system **100** is described herein with respect to the flow chart of FIG. **2**. In particular, a process **200** is schematically shown that involves first forming a computed tomography or other three dimensional planning image of an area of the patient that is known to contain an object of interest, such as a tumor, for treatment per process **210**. The planning image can be performed off-site or by using the computed tomography system **102** on-site. The three-dimensional information of the image of the general area of the tumor is then fed to computer **116** or another computer to compute a virtual three-dimensional radiation therapy plan per process **220** for varying table motion, gantry motion, fluence output rate, MLC orientation and shape of the MLC in order to apply a desired therapy dose to the tumor while reducing dosage to healthy tissue.

After the virtual plan is computed, the patient can now be treated with radiation in accordance with the plan. With that said, it should be kept in mind that the virtual plan assumes that the tumor will be positioned at the same spatial position when it was imaged per process **210**. When the patient is placed on the table **114** per process **230**, the spatial position of the tumor can be fine tuned per process **240** to be the same when it was imaged per process **210** in one of two manners. One manner for line tuning the spatial position is to have the technician reposition the patient until he or she visualizes that a skin marker on the patient is in the same position that it was when the image was taken per process **210**. A second manner of fine tuning is to take a three-dimensional image of the tumor using computed tomography system **102** and adjust the position of the patient so that the tumor shown in the fine tuning image will be repositioned to coincide with the position of the tumor determined per process **210**. Once the patient has been repositioned per process **240**, the virtual plan of process **220** is then applied to the tumor per process **250**.

Note that besides the fine tuning process mentioned previously, the treatment using the C-ARC plan can be performed in a real-time manner as described in U.S. Pat. Nos. 6,842,502 and 7,471,765, wherein real-time imaging of the tumor is performed during the radiation treatment and the real-time images of the tumor are used by computer **116** to control the table motion, the gantry motion, fluence output rate, MLC orientation and shape of the MLC.

An example of the above described real-time C-ARC treatment is schematically shown in FIG. **3**. In particular, a kV cone beam is directed through the patient on table **114** and a three dimensional real time image is generated on a flat panel imager **108**. In addition, an MV portal imager **120** is also simultaneously used to generate a real-time two-dimensional image of the patient based on the therapeutic radiation emitted by source **104** (not shown) that is positioned opposite the imager **120**. Such simultaneous real-time imaging by both kV cone beam projection imaging and MV portal imaging during therapeutic radiation delivery is made possible by taking advantage of the rotation features of VMAT and C-ARC in beam patient orientation. The projection images of MV portal imaging and kV cone beam projection imaging can be processed for 2D and 3D verification images, respectively, to monitor patient/anatomy position motion/variation in real-time during the therapeutic radiation treatment.

Examples of kV and MV portal images formed by the kV cone beam and MV imagers described above and at various gantry rotational positions are shown in FIGS. **5**A-D, wherein an area of a spine is being treated. Corresponding images of reference digitally reconstructed radiographic with beam's eye view are shown in FIGS. **4**A-D. (it represents the object within the beam direction and aperture)

With the above description of the C-ARC treatment plan, a comparison with other known treatment plans illustrates the advantages of the present invention. In the case of treatment of tumors in the breast via accelerated partial breast irradiation (APBI), the gantry **110** remains stationary at tangent angles while the table **114** rotates through one medial and one lateral arc, wherein the medial and lateral arcs are defined with respect to the orientation of the breast of the patient.

In the case of when the breast in question has been previously treated by a 3D-CRT plan, the beam arrangement of the 3D-CRT plan can be used to guide C-ARC planning, as it is deemed to have provided clinically acceptable dosimetry while avoiding any collision between the table, gantry, and the patient. The table positions from the 3D-CRT plan are taken as the limits of the table arcs. Similarly, the gantry position for each arc is chosen to be the same as that in the 3D-CRT plan. Optimization and dose calculation is done with control points positioned at 10° intervals along the arcs. Such breast treatment maintains the benefits of the standard tangent beam arrangement of APBI treated with 3D-CRT. C-ARC is a natural extension of the innovation of VMAT to the realm of breast radiotherapy, in which the standard tangent beam geometry minimizes dose outside the target. This is shown in FIGS. **6**A and **7**A where radiations beams using C-ARC are directed mostly to the breast and little radiation affects healthy organs, such as the heart and lungs. In contrast, APBI when applied with IMRT and VMAT can lead to beams being directed to health tissue as shown in FIGS. **6**B-C and **7**B-C.

In the comparison to follow, it regards patients previously treated with APBI via 3D-CRT and three additional and subsequent plans were generated for each patient: 1) a C-ARC plan, 2) an IMRT plan, and 3) a VMAT plan. The DVH parameters used for evaluation were taken largely from the normal tissue constraints of the NSABP-B39/RTOG 0413 protocol for breast therapy and are listed in Table 1 below:

7.8% on average (See FIG. **8**A). As shown, all three plans significantly decrease the ipsilateral lung V30%, but only the C-ARC and IMRT plans do so for the V5Gy (See FIG. **8**B). There are no significant reductions in the contralateral lung V5%. Four VMAT plans generate an unavoidably high Dmax in the contralateral breast that exceeds both the 3D-CRT plan and the normal tissue dose constraints outlined in the NSABP B-39/RTOG 0413 protocol (Table 1). None of the IMRT and C-ARC plans produce such violations. The C-ARC, IMRT, and VMAT plans all significantly reduce the number of monitor units compared with 3D-CRT, with the C-ARC plans prescribing the lowest mean number of MU (mean decrease: IMRT 136 MU, $p=0.013$, VMAT 281 MU, $p<0.001$, C-ARC 339 MU, $p<0.001$).

C-ARC and VMAT plans are also compared. These two planning modalities produce comparable reductions in the volume of ipsilateral breast receiving 50% and 100% of the prescribed dose, as well as the ipsilateral lung receiving 30% of the prescribed dose. However, VMAT plans result in significantly larger ipsilateral lung volumes receiving 5Gy (10.4% vs. 7.8%, $p=0.008$) and heart volumes receiving 192.5 cGy (7.7% vs. 5.5%, $p=0.021$). FIGS. **9**A-B show representative axial dose distributions for C-ARC and VMAT, respectively. As well, C-ARC plans prescribed a significantly lower number of monitor units compared to VMAT plans ($p=0.011$). A non-significant trend ($p=0.05$) emerged of the C-ARC plans delivering a lower Dmax to the contralateral breast.

In addition to reducing the dose to the ipsilateral breast, C-ARC plans decrease dose to the lung and heart. C-ARC and IMRT provided the greatest reductions in ipsilateral lung irradiation as measured by V5Gy due to their lack of en face

TABLE 1

Normal tissue dose constraints of the NSABP B-39/RTOG 0413 protocol and plan comparison parameters, mean values and range, for 3D-CRT, IMRT, C-ARC, and VMAT plans

NSABP B-39/ RTOC 0413 Normal Tissue Dose Constraints (1)	3D-CRT	C-ARC	p	IMRT	p	VMAT	p
Normal breast V50%	<60%	50.5% (39.5-61.1)	42.7%	<0.001 (35.1-49.2)	42.8%	<0.001 (34.6-50.6)	42.6%	<0.001 (33.7-52.7)
Normal breast V100%	<35%	20.2% (11.6-31.3)	17.0%	<0.001 (14.4-24.5)	16.6%	<0.001 (10.2-25.9)	15.8%	<0.001 (8.3-24.5)
Ipsilateral lung V30%	<15%	6.1% (0.3-10.0)	3.6%	0.004 (0.1-8.5)	3.5%	0.003 (0.2-8.2)	3.7%	0.002 (0.0-8.1)
Ipsilateral lung V5Gy	n/a	11.2% (1.2-17.6)	7.8%	0.001 (0.9-12.9)	7.7%	0.005 (1.0-13.0)	10.4%	0.381 (2.2-17.7)
Heart V5%	<5% for right-sided lesions <40% for left-sided lesions	6.8% (0.0-43.0)	5.5%	0.018 (0.0-39.1)	5.7%	0.018 (0.0-38.6)	7.7%	1 (0.0-39.5)
Contralateral breast Dmax	<3%	374.80 (58.10-2451.20)	260.97	0.006 (56.30-1841.60)	198.25	0.002 (54.5-1364.00)	288.24	0.424 (86.30-1529.20)
Monitor Units	n/a	827.21 (607.45-1084.30)	488.31	<0.001 (448.40-525.90)	691.33	0.013 (555.00-928.30)	546.44	<0.001 (484.40-667.00)
Control Points	n/a	4		9-14		23-25		18-20

Table 1 above lists the mean values for the normal tissue doses of the C-ARC, IMRT, and VMAT plans, all of which are compared to the original 3D-CRT plan. All three treatment planning modalities significantly decrease the volume of normal ipsilateral breast tissue V50%, reducing this value by geometry. C-ARC and IMRT plans also produced significant reductions in low dose irradiation of the heart.

Due to a lack of wedges, the C-ARC, IMRT, and VMAT plans all reduced the number of monitor units prescribed in comparison to the 3D-CRT plans, with C-ARC plans provid-

ing the greatest reduction. C-ARC plans also used the smallest number of control points, thereby minimizing leakage radiation.

As shown in Table 1, C-ARC plans produce a significant reduction in ipsilateral breast irradiation without increasing dose to the lungs, heart, and contralateral breast. VMAT plans are also able to reduce radiation dose to the ipsilateral breast, but this can come more often at the expense of increased dose elsewhere.

A natural extension of VMAT, C-ARC will allow for treatment with improved conformality, decreased delivery of monitor units, and anticipated shorter treatment times. The complexity of C-ARC is not significantly greater than that of existing arc therapy from the point of view of the treatment planner and operator. In order for this innovation to take place it will be necessary to link couch rotation control to dose rate and multileaf collimator motion. Minor modification of VMAT planning software will also be required to incorporate couch arcs.

In the case of APBI C-ARC therapy, the gantry **110** is stationary while the table **114** moves. There are instances where C-ARC therapy can involve simultaneous movement of the table **114** and the gantry **110**. An example of this is when partial brain radiation therapy is employed. Movement of the table **114** and gantry **110** allows for the amount of therapeutic radiation applied to the healthy areas involving the optic chlasm, optic nerve and brain stem. Indeed, when compared with IMRT, C-ARC therapy employs reduced mean and maximum dosages for the optic chlasm, optic nerve and brain stem when compared with IMRT

From the foregoing description, one skilled in the art can readily ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and/or modifications of the invention to adapt it to various usages and conditions.

We claim:

1. A system for radiotherapy comprising:

a couch having a top lateral surface upon which a patient being treated by the system is positioned, the couch having continuous arc rotation for delivery of accelerated irradiation to the patient;

wherein the couch is movable rotationally and translationally; and

wherein delivery of the accelerated irradiation is performed during at least a portion of the movement.

2. The system of claim **1**, wherein the couch has continuous translation for delivery of accelerated irradiation to the patient.

3. The system of claim **1**, wherein the couch is rotatable at least about a z-axis orthogonally extending through a lateral surface of the couch, and the radiation is delivered during at least a portion of the rotation about the z-axis.

4. The system of claim **1**, wherein the couch is rotatable at least about a y-axis extending through a lateral surface of the couch, and the radiation is delivered during at least a portion of the rotation about the y-axis.

5. The system of claim **1**, further comprising an imaging system to generate image information that identifies an object of interest within the patient to be treated by the accelerated irradiation.

6. The system of claim **5**, wherein the image information is formed in a real-time manner during the continuous rotation of the couch and such image information is used to control continuous rotation of the couch in a real-time manner.

7. The system of claim **2**, further comprising an imaging system to generate image information that identifies an object of interest within the patient to be treated by the accelerated irradiation.

8. The system of claim **7**, wherein the image information is formed in a real-time manner during the continuous rotation and translation of the couch and such image information is used to control continuous rotation and translation of the couch in a real-time manner.

9. The system of claim **1**, wherein the continuous rotation of the couch is based on image information of the patient generated prior to the patient being placed on the couch.

10. The system of claim **2**, wherein the continuous rotation and continuous translation of the couch is based on image information of the patient generated prior to the patient being placed on the couch.

11. A radiation therapy system comprising:

a radiation source that moves about an object and directs a beam of radiation towards the object;

a multi-leaf collimator comprising a plurality of movable leaves that define an aperture through which the beam is directed from the radiation source to the object;

a table upon which the object is positioned, the table being translationally and rotationally movable; and

a computer in communication with the radiation source, the multi-leaf collimator and the table, wherein the computer simultaneously controls one or more of the following parameters of the radiation source, the multi-leaf collimator and the table: table motion, radiation source motion, fluence output rate, multi-leaf collimator orientation and shape of the aperture;

wherein the computer is configured to cause delivery of the radiation during at least a portion of the movement of the table.

12. The system of claim **11**, wherein the table is rotatable at least about a z-axis orthogonally extending through a lateral surface of the table, and the radiation is delivered during at least a portion of the rotation about the z-axis.

13. The system of claim **11**, wherein the table is rotatable at least about a y-axis extending through a lateral surface of the table, and the radiation is delivered during at least a portion of the rotation about the y-axis.

14. The system of claim **11**, wherein the table is rotatable at least about an x-axis extending through a lateral surface of the table, and the radiation is delivered during at least a portion of the rotation about the x-axis.

15. The system of claim **11**, wherein the object is a tumor.

16. The system of claim **11**, further comprising an imaging system to generate image information that identifies an orientation of the object.

17. The system of claim **16**, wherein the image information is formed in a real-time manner during rotational and translational movement of the table and such image information is used to simultaneously control one or more of the following parameters in a real time manner: table motion, table motion speed, radiation source motion, fluence output rate, multi-leaf collimator orientation and shape of the aperture.

18. The system of claim **16**, wherein simultaneous control of one or more of the following parameters table motion, radiation source motion, fluence output rate, multi-leaf collimator orientation and shape of the aperture is performed based on image information of the object generated prior to a patient containing the object being positioned on the table.

19. A method of providing radiation comprising:

directing a beam of radiation towards an object;

defining an aperture through which the beam is directed to the object;

positioning a table having a top lateral surface upon which the object lies;

rotating the table at least about an axis thereof, wherein the beam of radiation is delivered to the object at least during a portion of the rotating; and

simultaneously controlling, during the rotation, one or more of the following parameters: table motion, beam motion, fluence output rate, aperture orientation and shape of the aperture.

20. The method of claim **19**, wherein the rotation is about a z-axis orthogonally extending through a lateral surface of the table.

21. The method of claim **19**, wherein the rotation is about a y-axis extending through a lateral surface of the table.

22. The method of claim **19**, wherein the rotation is about an x-axis extending through a lateral surface of the table.

23. The method of claim **19**, further comprising translating the table along an axis thereof, wherein the beam of radiation is delivered to the object at least during a portion of the translating.

24. The method of claim **19**, further comprising generating image information that identifies an orientation of the object.

25. The method of claim **24**, wherein the image information is formed in a real-time manner during rotational and translational movement of the table and such image information is used to simultaneously control one or more of the following parameters in a real time manner: table motion, beam motion, fluence output rate, aperture orientation and shape of the aperture.

26. The method of claim **19**, wherein the generating image information is performed prior to a patient containing the object being positioned on the table, and wherein the simultaneously controlling is based on the image information.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

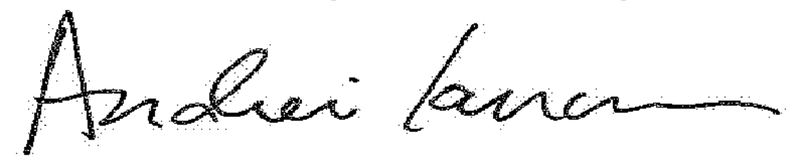
PATENT NO. : 9,320,917 B2
APPLICATION NO. : 14/106327
DATED : April 26, 2016
INVENTOR(S) : Di Yan and Alvaro Martinez

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

The Title of the invention should read as follows:
Intensity Modulated Arc Therapy with Continuous Couch Rotation/Shift and Simultaneous Cone Beam Imaging

Signed and Sealed this
Twentieth Day of February, 2018



Andrei Iancu
Director of the United States Patent and Trademark Office